

Do Tax Cuts Increase Consumption? An Experimental Test of Ricardian Equivalence

Thomas Meissner*
Davud Rostam-Afschar**



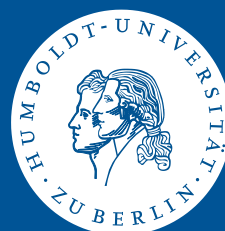
* Humboldt-Universität zu Berlin, Germany

** Freie Universität Berlin, Germany

This research was supported by the Deutsche
Forschungsgemeinschaft through the SFB 649 "Economic Risk".

<http://sfb649.wiwi.hu-berlin.de>
ISSN 1860-5664

SFB 649, Humboldt-Universität zu Berlin
Spandauer Straße 1, D-10178 Berlin



Do Tax Cuts Increase Consumption?

An Experimental Test of Ricardian Equivalence*

Thomas Meissner[†]
Davud Rostam-Afschar[‡]

July 12, 2014

Abstract

This paper tests whether the Ricardian Equivalence proposition holds in a life cycle consumption laboratory experiment. This proposition is a fundamental assumption underlying numerous studies on intertemporal choice and has important implications for tax policy. Using nonparametric and panel data methods, we find that the Ricardian Equivalence proposition does not hold in general. Our results suggest that taxation has a significant and strong impact on consumption choice. Over the life cycle, a tax relief increases consumption on average by about 22% of the tax rebate. A tax increase causes consumption to decrease by about 30% of the tax increase. These results are robust with respect to variations in the difficulty to smooth consumption. In our experiment, we find the behavior of about 62% of our subjects to be inconsistent with the Ricardian proposition. Our results show dynamic effects; taxation influences consumption beyond the current period.

Keywords Ricardian Equivalence · Taxation · Life Cycle · Consumption · Laboratory Experiment

JEL Classification D91 · E21 · H24 · C91

*The authors thank Frank Heinemann and Viktor Steiner for valuable comments. We are grateful to Satpal Nijjar for programming assistance in setting up the experimental software. Financial support from the Einsteinstiftung Berlin through the Berlin Doctoral Program in Economics and Management Science (BDPEMS) as well as from the Deutsche Forschungsgemeinschaft (DFG) through CRC 649 “Economic Risk” is gratefully acknowledged. The program code and the dataset that generated all of the results in this paper are available on the authors’ websites, <http://rostam-afshar.de> or <http://tmeissner.com>.

[†]Technical University of Berlin, Chair of Macroeconomics (H 52), Straße des 17. Juni 135, 10623 Berlin, Germany (e-mail: meissnet@gmail.com).

[‡]Department of Economics, Freie Universität Berlin, Boltzmannstr. 20, 14195 Berlin, Germany, and German Institute for Economic Research (DIW Berlin) (e-mail: davud.rostam-afshar@fu-berlin.de).

1 Introduction

The most common definition of Ricardian Equivalence states that consumption decisions are not affected by whether a government’s refinancing scheme is based on taxes or debt.¹ The proposition has been tested in numerous econometric settings. While the excellent survey by [Seater \(1993\)](#) suggests that the data support Ricardian Equivalence, various open questions remain because of factors that are hard to control for when using survey or register data like income uncertainty, individual risk and time preferences.

Therefore, we study a question that is derived from the Ricardian proposition, namely whether tax cuts increase consumption, in a laboratory experiment in which the maintained assumptions of the underlying theory can be ensured to hold. In particular, one can guarantee with certainty that the government budget is balanced at the end of a life cycle. This is arguably never the case for life cycles observed outside the laboratory.²

Beyond inference from survey data, some previous experimental work does exist on Ricardian Equivalence. However, to our knowledge these studies all use overlapping generations (OLG) models as a theoretical basis for the experimental design ([Cadsby and Frank \(1991\)](#), [Slate, McKee, Beck, and Alm \(1995\)](#), [Di Laurea and Ricciuti \(2003\)](#), [Adj, Alm, and Ferraro \(2009\)](#)). In contrast, we use a life cycle model of consumption to test the Ricardian Equivalence proposition in a richer experimental environment that involves multi-period optimization. Existing experimental literature suggests that subjects do not behave optimally when dealing with dynamic

¹See [Musgrave \(1985\)](#) and [Barro \(1974\)](#) for early treatments.

²Note that in our setting a balanced government budget is not necessary for Ricardian Equivalence, but it suffices that the sum of taxes remains constant over an individual’s life cycle, which is also hardly observed in reality.

optimization problems such as intertemporal consumption/saving problems. While this issue affects consumption choices in real life, and could cause a violation of Ricardian Equivalence, it is hardly possible to test it in a three-period model. Moreover, other factors that are generally known to affect consumption in a dynamic context, such as risk aversion and precautionary saving, have no influence on optimal consumption behavior in the mentioned OLG models. A further motivation for using a multi-period life cycle model of consumption is the possibility for analyzing dynamic effects of taxation. A tax cut in one period may influence consumption beyond that period. To the best of our knowledge, dynamic effects of taxation have not yet been analyzed in experimental tests of Ricardian Equivalence.

In our experiment, a Ricardian tax scheme is implemented as a tax cut in early periods of the experiment, followed by a tax increase of the same magnitude in later periods. Introducing such a tax scheme may increase the difficulty to smooth consumption for subjects, since net income can have a higher sample variance with Ricardian taxation compared to a tax scheme with constant taxes over the life cycle. Hence, any observed effects could potentially result from increased difficulty rather than a violation of the Ricardian proposition. We therefore introduce two different taxing schemes, one that increases the difficulty to smooth consumption and one that decreases it relative to a control treatment with constant taxation. In this way we can distinguish the effects of difficulty and Ricardian taxation separately. This is a novel approach with regard to existing experimental studies on Ricardian Equivalence.

Our first main finding is that Ricardian taxation *does* influence consumption decisions. A nonparametric analysis shows that deviations from optimal consumption appear to be larger with the tax scheme that increases the difficulty to smooth consumption compared to the one that decreases the difficulty. Overall, deviations from optimal behavior are lowest in the treatment with constant taxation. This implies that both difficulty and Ricardian taxation affect consumption behavior.

Our second main result is that a tax benefit in early periods increases consumption by about 22% of the tax benefit on average, while a tax increase reduces consumption by 30% of the tax increase. These results are robust to variations in the difficulty to smooth consumption. We find this by using panel data methods to estimate consumption functions as derived in [Caballero \(1990, 1991\)](#), extended to include taxes.

Our third main result is that about 62% of the subjects in our sample do not behave according to the Ricardian proposition in a conservative estimation. This finding is similar to the findings in other studies ([Campbell and Mankiw, 1991](#); [Shapiro and Slemrod, 1995](#)) that employ very different methods.

Moreover, our findings suggest that the role of fiscal policy might be of greater importance than currently presumed. In fact, our analysis rejects the hypothesis that fiscal policy does not influence consumption behavior. With the caveat that more theoretical and empirical research is needed to precisely quantify the effects of tax cuts, we conclude that the rejection of Ricardian Equivalence, in turn, implies that fiscal policy could use tax cuts in times of economic slowdown as a means to stimulate consumption.

The remainder of this paper is structured as follows. Section 2 describes the experimental design and the underlying theory. Section 3 reports our results. Section 4 concludes.

2 Theory and Experimental Design

The experiment described in the following section is based on an adapted version of the life cycle model of consumption used in [Meissner \(2013\)](#). We specified this model in order to make the experimental environment as tractable as possible for the subjects without making it trivial. One experimental life cycle lasts for $T = 25$

periods. In each period $t = (1, \dots, T)$, subjects decide how much to consume (c_t) and implicitly how much to save or borrow. There is no discounting, and no interest is paid on savings or debt. Period income y_t follows an i.i.d. stochastic process and takes the values of 120 or 250 with equal probability in each period. Subjects have to pay a lump sum tax τ_t in every period. The government's budget constraint requires the total taxes to be collected during the experiment to equal ϑ . The subjects' intertemporal budget constraint requires period consumption plus period savings (a_{t+1}) plus period taxes to equal period wealth, which is defined as $w_t = y_t + a_t$. Period savings are allowed to be both positive and negative. Savings in the last period (a_{T+1}) must equal zero, which implies that remaining wealth must be consumed in that period. Subjects start with initial savings, $a_1 = 1000$.³

Induced preferences are given by a time-separable CARA utility function: $u(c_t) = 338(1 - e^{(-0.0125c_t)})$.⁴⁵ The subjects' objective is to choose consumption in every period to maximize the expected utility of life-time consumption. The decision problem subjects face at any period t can be written as:

$$\max_{c_t} E_t \sum_{j=0}^{T-t} u(c_{t+j}) \quad (1)$$

³One often-stated reason for the violation of Ricardian Equivalence is borrowing constraints. In order to avoid a failure of Ricardian Equivalence by design our model has no borrowing constraints. Implicit borrowing constraints, such as debt aversion (see [Meissner \(2013\)](#)), might have a similar effect. To rule out these effects we endow subjects with a positive level of wealth at the beginning of the experiment.

⁴CARA utility was chosen because this class of utility functions is defined in the negative domain. Why this is of importance will be explained later in this section. Using CARA preferences we connect to [Caballero \(1990, 1991\)](#) and other studies on experimental life cycle consumption/savings problems that also make use of CARA utility. See, for instance, [Carbone and Hey \(2004\)](#).

⁵We chose the parameters of our model in order to make the payoff function as tractable as possible, while ensuring a hourly wage that complies with the rules of the laboratory, see Section 2.2 and Appendix B.

$$\text{s.t. } c_t + a_{t+1} + \tau_t = w_t, \quad (2)$$

$$a_1 = 1000, \quad a_{T+1} = 0, \quad (3)$$

$$\sum_{t=1}^T \tau_t = \vartheta. \quad (4)$$

With CARA utility, this optimization problem can be solved analytically (Caballero (1990, 1991)). Optimal consumption in period t is equal to⁶:

$$c_t^*(w_t) = \frac{1}{T-t+1} [w_t + (T-t)y_p - \mathcal{T}_t - \Gamma_t(\theta\sigma_y)]. \quad (5)$$

$$\Gamma_t(\theta\sigma_y) = \sum_{j=0}^{T-t} \sum_{i=1}^j \frac{1}{\theta} \log \cosh \left[\frac{\theta\sigma_y}{T-t+1-i} \right]. \quad (6)$$

$$\mathcal{T}_t = \sum_{j=0}^{T-t} \tau_{t+j} = \vartheta - \sum_{j=1}^{t-1} \tau_j. \quad (7)$$

In equation (5) y_p denotes permanent income, which is equal to the mean of the income process, i.e. 185. The coefficient of absolute risk aversion, θ , is set to 0.0125, and $\sigma_y = 65$ is one standard deviation of the income process. Equation (6) is the term for precautionary saving.

Note that with respect to tax payments, optimal consumption only depends on the *sum* of current and all future tax payments, \mathcal{T}_t . Therefore, a tax cut in period t will not affect current optimal consumption. This is because any tax cut must be followed by a later increase in taxes of the same magnitude to permit the government intertemporal budget constraint to hold. In the period after a tax cut, wealth will be higher compared to the same situation without a tax cut in the previous period. This higher wealth, in turn, is offset by the sum of current and future tax payments

⁶See Appendix A for the derivation of optimal consumption.

\mathcal{T}_t , which increases by the same amount, leaving optimal consumption unchanged. This implies that the size and order of each of the single lump sum tax payments $\tau = (\tau_1, \tau_2, \dots, \tau_T)$ plays no role with respect to optimal consumption, as long as the sum of tax payments over the life cycle is kept constant. This is the definition of Ricardian Equivalence in our experimental environment.

In order to test Ricardian Equivalence, we vary the temporal structure of tax payments, while keeping the sum of taxes to be paid over the experimental life cycle constant. Since optimal consumption is not affected by this variation, we can directly compare consumption decisions under different tax schemes.

2.1 Treatments

The basic idea of a Ricardian experiment in our framework is a tax cut in early periods of the experimental life cycle that is financed by a tax increase in later periods (Seater (1993)). To isolate the effect of Ricardian taxation we first run a control treatment in which tax payments are kept constant at 120 in all periods ($\vartheta = 3000$). This treatment will be compared to treatments that resemble a Ricardian tax scheme specified in more detail below.

All existing experimental studies on life cycle consumption models find that subjects have difficulties smoothing consumption optimally over the life cycle. In particular, a larger variance of income leads to a deterioration of consumption decisions (Ballinger, Palumbo, and Wilcox (2003)). Moreover, a change in income uncertainty is known to affect consumption decisions through adjustments in precautionary demand for wealth (Zeldes (1989); Rostam-Afschar and Yao (2014)).

A potential concern in our experiment is that it may be harder to smooth consumption with a Ricardian tax scheme in comparison to the control treatment. The introduction of a Ricardian tax scheme might increase the variance of *net* income, compared to the treatment with a constant tax. Differences in behavior between the

control and the Ricardian treatment could therefore arise from the increased level of difficulty to smooth consumption. It would be misleading to interpret this observation as evidence against Ricardian Equivalence. In theory, however, the variance of income does not change when a Ricardian tax scheme is introduced. Even the theoretical variance of *net* income remains the same since taxes are lump sum, and the sum of taxes that have to be paid over the course of the experiment is deterministic and constant across treatments.

However, introducing a Ricardian tax may increase the *sample* variance of observed net income. This increase might change the difficulty to smooth consumption for our subjects. Substantial evidence exists that consumption tracks income too closely in experiments on life cycle consumption (see [Ballinger, Palumbo, and Wilcox \(2003\)](#), [Carbone and Hey \(2004\)](#)).

A Ricardian tax scheme can increase the distance between *net* income and optimal consumption, and therefore it might make it harder for subjects to smooth consumption. To account for this, we design two Ricardian treatments that differ with respect to the difficulty to smooth consumption. In this way, we can identify the effect that difficulty has on consumption decisions. This enables us to distinguish the effect of Ricardian taxation from the difficulty of smoothing consumption.

Period	Income		Control		Ricardian 1		Ricardian 2		$c_t^*(w_t^*)$
	Realization	Taxes	Net Income	Taxes	Net Income	Taxes	Net Income	Taxes	
1	120	120	0	0	120	120	0	120	98.53
2	120	120	0	0	120	120	0	120	95.87
3	120	120	0	0	120	120	0	120	93.09
4	120	120	0	120	0	120	0	120	90.19
5	250	120	130	120	130	0	250	0	93.35
6	250	120	130	120	130	0	250	0	96.67
7	120	120	0	120	0	120	0	120	93.32
8	120	120	0	120	0	120	0	120	89.79
9	250	120	130	120	130	0	250	0	93.70
10	120	120	0	120	0	120	0	120	89.74
11	250	120	130	120	130	120	130	120	94.19
12	250	120	130	120	130	120	130	120	98.97
13	250	120	130	120	130	120	130	120	104.13
14	120	120	0	120	0	120	0	120	98.89
15	250	120	130	120	130	120	130	120	105.02
16	120	120	0	120	0	120	0	120	98.79
17	120	120	0	120	0	120	0	240	91.89
18	250	120	130	240	10	120	130	120	100.43
19	250	120	130	240	10	120	130	120	110.25
20	250	120	130	240	10	120	130	120	121.81
21	250	120	130	120	130	120	130	120	135.87
22	250	120	130	120	130	120	130	120	153.75
23	120	120	0	120	0	240	120	240	134.99
24	250	120	130	120	130	120	130	120	173.91
25	120	120	0	120	0	240	120	240	132.84
Mean (Round)	187.6	120	67.6	120	67.6	120	67.6	120	107.6
Variance (Round)	4,394	0	4,394	3,600	4,094	3,600	11,894	3,600	489
Mean (All)	185	120	65	120	65	120	65	120	105
Variance (All)	4,246.2	0	4,246.2	3,473.4	3,956.8	3,473.4	11,482.4	3,473.4	383.6
$E[(y - \mu_y)^2]$	4,225		4,225		4,225		4,225		

Table 1: The Different Tax Schemes for One Exemplary Realization of the Income Stream.

In the first Ricardian treatment (Ricardian 1) tax cuts in the beginning of the experiment are only given when subjects observe a *low* (i.e. $y_t = 120$) income realization. Analogously, tax increases in the later periods of the experiments are only implemented when subjects observe a *high* (i.e. $y_t = 250$) income realization. In this way, the sample variance is *smaller* compared to the control treatment (see Table 1). If subjects react to changes in net income, this treatment should be easier to play than the control treatment, because this taxing scheme essentially smooths net income.

In the second Ricardian treatment (Ricardian 2) tax cuts in the beginning of the experiment are only received when subjects observe a *high* income realization. Tax increases in later periods are only implemented when subjects observe a *low* income realization. The *larger* sample variance of net income therefore arguably makes it harder for subjects to smooth consumption. Table 1 shows the different tax schemes for one exemplary realization of the income stream.

We repeat the experiment for a total of eight rounds. Each subject plays eight repetitions of the same treatment, though with a different realization of the income process in each round. Using this approach we are able to assess learning behavior. Moreover, we increase the robustness of our findings by ensuring that observed behavior is not merely an artifact of one particular realization of the income process. At any given period during the experiment, subjects in the different treatments observe the same realization of the income process. In this way, we can directly compare behavior between subjects across treatments. This is because optimal consumption is the same across treatments when the same realization of the income stream is observed.

2.2 Experimental Procedures

The experiment was programmed and conducted with the software z-Tree ([Fischbacher \(2007\)](#)). The experimental software is an adapted version of the software used in [Meissner \(2013\)](#).⁷ In the instructions, consumption was explained to the subjects as buying “points” by spending the experimental currency “Taler”, in which income was denoted. The experimental currency was converted to points by the utility function specified above. Subjects were informed about the exact form of the utility function. Furthermore, they were given a graph of the function and a table with relevant function values. The advantage of framing consumption as buying points is that negative consumption can be explained as selling points in return for experimental currency.

At the beginning of the experiment, subjects were given time to read the instructions, which were then read aloud by the experimenter. After this, subjects completed a quiz about the content of the instructions. The correct answers to all questions were then read aloud before subjects started the actual experiment.

In each period of the experiment, subjects were asked to input consumption decisions in an interface that displayed period income, savings from the last period, wealth, and taxes. The interface showed the history of all previous decisions and relevant values, such as savings, wealth, taxes, the sum of taxes paid so far, and the number of purchased points and accumulated points. Before a consumption decision was submitted, subjects were informed about how it would translate into points and the amount of savings that would be available in the next period. After this information was displayed, subjects had the opportunity to start over; that is, they could specify a different level of consumption and check its implications. In the final period of each life cycle, the program automatically spent that period’s

⁷A screenshot of the experimental interface is provided in [Appendix B](#).

wealth minus taxes as consumption. Then, subjects were informed on a separate screen about the amount of points they purchased during the round. At the end of the experiment, two of the eight experimental life cycles were randomly chosen to be payoff relevant. After the actual experiment subjects were asked to fill out a questionnaire that contained incentivized lottery choices, which assessed individual risk aversion.

Subjects' payoffs were determined by a pre-announced linear function of the amount of points purchased in the two relevant rounds. Subjects received a show-up fee of 5 Euro and earned 17.79 Euro on average.

The experiment was conducted at the laboratory of the Technical University of Berlin. Subjects were recruited using ORSEE (see [Greiner \(2004\)](#)). A total of 133 subjects participated. Most of the subjects were undergraduate students in the field of economics or engineering. About one third of the subjects were female.

3 Data Analysis

To identify the effect that a tax cut has on consumption, we employ two strategies. First, we directly compare deviations from optimal behavior across treatments to identify treatment effects. Second, we run panel regressions to measure the effect of taxes on the deviation from optimal consumption. We drop all rounds in which subjects consume less than -100 (< 1 st percentile) or more than 500 (> 99 th percentile) in any period of the round.⁸

⁸Subjects with consumption above 500 or below -100 could hardly recover from the associated utility loss, and therefore had no incentive to choose one spending decision over another. Since consumption choice is dependent within rounds, we had to drop all consumption choices of the round in which subjects consumed more than 500 or less than -100. The amount of dropped rounds is roughly equally distributed across all three treatments.

3.1 Deviations from Optimal Behavior

As a first step in analyzing our experimental data, we examine deviations from optimal behavior. Deviations from optimal consumption can be assessed with the following measure (see [Ballinger, Palumbo, and Wilcox \(2003\)](#), [Meissner \(2013\)](#)):

$$m_1 = \sum_{t=1}^T |c_t^*(w_t) - c_t| \quad (8)$$

where $c_t^*(w_t)$ is conditionally optimal consumption (depending on current wealth w_t), and c_t is observed consumption in period t . This measure is the sum of absolute deviations from conditionally optimal consumption for one subject and over one experimental life cycle. Indices for subjects and rounds are dropped to facilitate legibility. As already discussed, all subjects observe the same realizations of the income stream. Therefore we can also compare deviations from unconditionally optimal consumption. We do this by use of the following measure:

$$m_2 = \sum_{t=1}^T [u(c_t^*(w_t^*)) - u(c_t)], \quad (9)$$

where $c_t^*(w_t^*)$ denotes unconditionally optimal consumption at period t as a function of optimal period wealth w_t^* . This measure can be interpreted as the utility loss that results from suboptimal consumption. With this measure we can assess the effect of Ricardian taxation on welfare in our experimental environment.

Figure 1 shows the medians and means of the measures m_1 and m_2 by treatments and rounds. At first glance subjects appear to perform best in the Control treatment. Subjects in the Ricardian 2 treatment appear to have higher deviations from optimal consumption and a higher utility loss compared to subjects in the Control treatment. Subjects in the Ricardian 1 treatment seem to be somewhere between the Control and Ricardian 2 treatments. This intuition can be confirmed by examining the total

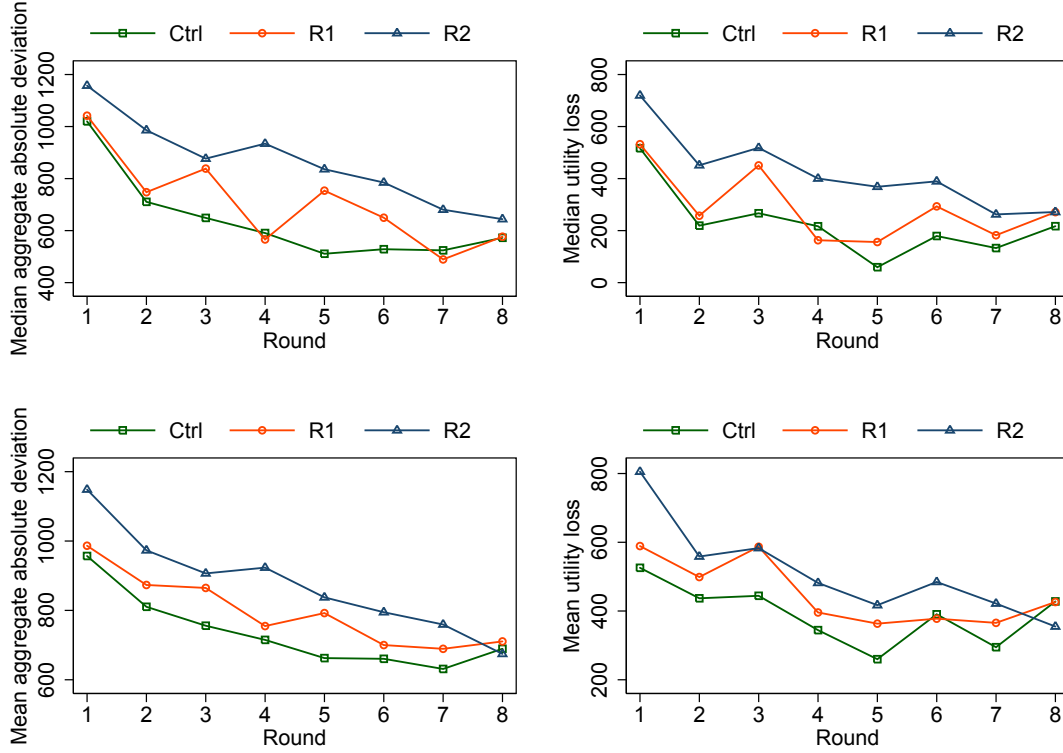


Figure 1: Medians and Means of Aggregate Absolute Deviations from Optimal Consumption (m_1) in Taler and Utility Loss (m_2) in points by Treatments and Rounds.

effect; that is, the measures m_1 and m_2 averaged for each subject over the eight rounds of the experiment. For both measures, subjects perform significantly better in the Control treatment compared to subjects in Ricardian 1 (p-values from a Mann-Whitney U-test are provided in Table 2). Subjects in the Ricardian 2 treatment have significantly higher absolute deviations from optimal consumption and higher utility loss compared to both Ricardian 1 and Control (see column *Total* in Table 2).

Examining the differences across treatments in the specific rounds reveals that this relationship is significant for most, but not all rounds. Absolute differences from optimal consumption (measure m_1) are significantly higher in Ricardian 2 compared

		Round							
	Total	1	2	3	4	5	6	7	8
Median									
m1 Ctrl	586.37	1020.06	710.63	648.85	590.71	511.04	528.51	524.14	572.39
m1 R1	696.93	1041.94	747.77	838.44	565.97	753.62	649.57	489.26	576.53
m1 R2	848.90	1157.44	985.97	876.65	934.42	835.99	785.01	680.49	644.13
Mean									
m1 Ctrl	732.89	956.95	810.44	755.91	715.01	662.57	660.47	631.25	689.43
m1 R1	788.37	986.54	873.30	864.78	754.91	792.37	700.07	689.25	710.61
m1 R2	866.04	1148.53	973.18	906.70	923.39	837.70	794.79	759.42	674.53
p-Value									
R1-Ctrl	0.00	0.82	0.00	0.00	0.52	0.00	0.04	0.25	0.23
R2-Ctrl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67
R1-R2	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.25
Median									
m2 Ctrl	210.79	516.72	219.06	266.78	216.78	59.27	179.26	132.85	216.98
m2 R1	288.05	532.20	257.17	450.73	162.96	156.07	293.17	182.22	271.07
m2 R2	389.49	719.71	451.17	518.33	400.28	368.53	389.49	262.35	271.44
Mean									
m2 Ctrl	389.79	525.78	437.03	444.28	344.41	259.92	390.52	294.73	427.96
m2 R1	444.73	589.00	498.80	587.03	395.80	363.34	377.77	365.57	426.21
m2 R2	502.01	805.39	558.59	583.06	481.79	417.04	484.61	421.83	354.83
p-Value									
R1-Ctrl	0.00	0.18	0.00	0.00	0.35	0.00	0.91	0.19	0.82
R2-Ctrl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.71
R1-R2	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.78

Notes: P-values were calculated by use of Mann-Whitney U-tests.

Source: Own calculations based on data from our experiment.

Table 2: Medians and Means of the Measures m_1 and m_2 by Treatments and Rounds.

to Control in all but the last rounds. The picture is not as clear when comparing m_1 between Ricardian 1 and Control. Here, m_1 is significantly higher in Ricardian 1 compared to Control in four out of eight rounds. Comparing m_1 between Ricardian 1 and Ricardian 2 reveals that absolute deviations from optimal consumption are significantly higher in Ricardian 2 in all but the last round. Overall this finding confirms the above intuition, though the evidence is not very strong in comparing Ricardian 1 and Control at the round level.

Comparing measure m_2 (utility loss) at the round level across the three different treatments yields similar results. Utility loss is significantly higher in Ricardian 2 than in Control in all but the last round. Measure 2 is significantly higher in Ricardian 1 compared to Control in three out of eight rounds. With respect to the Ricardian treatments, utility loss in Ricardian 2 is significantly higher than in Ricardian 1 in six out of eight rounds.

Deviations from optimal consumption as well as utility loss appear to decline over the eight rounds of the experiment. This finding would imply that subjects learn to improve their consumption decisions by repeating the experiment.⁹

In summary, subjects in treatments with Ricardian taxation have higher deviations from optimal consumption and a higher utility loss than subjects in the Control treatment. Moreover, subjects with a net income stream that is difficult to smooth (Ricardian 2) appear to perform worse than subjects with a net income stream that is easy to smooth. These findings imply that subjects react to both difficulty to smooth consumption and Ricardian taxation. However, the finding that subjects in Ricardian 1 appear to perform worse than subjects in the Control treatment suggests that the effect of Ricardian taxation outweighs that of the decreased difficulty

⁹We acknowledge that learning effects are likely present in our experiment, without a further formal analysis. This would be beyond the scope of this paper, and such effects have already been shown repeatedly in a variety of other experiments on dynamic intertemporal optimization problems (see [Duffy \(2012\)](#) for an excellent survey).

to smooth consumption. One mechanism that would result in such a finding is that subjects do not internalize the government budget constraint but instead treat a tax benefit as additional wealth.

3.2 Panel Regression

In order to assess the magnitude of the effect that Ricardian taxation has on consumption we run panel regressions. Our baseline specification derived from equation (5) is

$$c_{itr} = \beta_1 \tilde{y}_{tr} + \beta_2 \tilde{a}_{itr} + \beta_3 (T - t) \tilde{y}_p - \beta_4 \tilde{\mathcal{T}}_{itr} + \beta_5 \tilde{\Gamma}_{tr}(\theta \sigma_y), \quad (10)$$

for all subjects $i = 1, \dots, 127$, periods $t = 1, \dots, 25$, and rounds $r = 1, \dots, 8$ where $\tilde{F} = \frac{1}{(T-t+1)}F$, and F represents the variables of equation (5). We transform the regressors that are derived from the theoretical consumption function in this way to account for the time dependency of optimal consumption. Moreover, this simplifies the interpretation of the corresponding coefficients. If subjects behave optimally, or deviate randomly from optimal consumption, e.g. due to calculation errors, the estimated coefficients β_1 to β_5 should be time invariant and equal to one. In equation (11), we extend our baseline specification to account for tax effects by including dummy variables indicating a tax rebate $d_{0,\text{tx}}$ and a tax increase $d_{240,\text{tx}}$. To identify dynamic effects of taxation, we include dummy variables that indicate whether the tax cut (increase) occurred in the previous period $d_{t-1,0,\text{tx}}$ ($d_{t-1,240,\text{tx}}$) or up to three periods ago. Moreover, we control for treatment using treatment dummies ($dR1, dR2$) and subject characteristics X_i such as risk preference, gender, and subject of academic study¹⁰. Finally, we account for round effects and include a constant,

¹⁰Subjects who are not students, i.e. unemployed or employees, are subsumed under *other* in Table 3.

period, and period squared. The latter two variables should capture any time trend that is beyond the theoretical. Since all these additional regressors do not show up as variables in the optimal consumption function, the corresponding coefficients should not be significantly different from zero if subjects behave optimally or deviate randomly from optimal consumption.

$$\begin{aligned}
c_{itr} = & \beta_1 \tilde{y}_{tr} + \beta_2 \tilde{a}_{itr} + \beta_3 (T - t) \tilde{y}_p - \beta_4 \tilde{\mathcal{T}}_{itr} + \beta_5 \tilde{\Gamma}_{tr}(\theta \sigma_y) \\
& + \beta_{0.tx} d_{0.tx} + \beta_{240.tx} d_{240.tx} + \sum_{j=1}^3 \beta_{t-j,0.tx} d_{t-j,0.tx} + \sum_{j=1}^3 \beta_{t-j,240.tx} d_{t-j,240.tx} \\
& + \beta_6 dR1_i + \beta_7 dR2_i + \beta_8 X_i + \sum_{k=1}^8 \beta_{r.k} d_{r.k} + \beta_9 t + \beta_{10} t^2 + \text{constant}.
\end{aligned} \tag{11}$$

Table 3 shows what factors are associated with observed consumption (c_{itr}).¹¹ Individual specific characteristics, such as ability to use computer software, could bias our estimates. To obtain consistent results, we estimate a fixed effects (FE) specification that is presented along with the OLS specification. In both regressions the same set of regressors are included. Moreover, both specifications are estimated with robust standard errors clustered on the subject level.

Our specification allows us to test whether subjects behave according to the theoretical prediction of our consumption life cycle model, at least for those variables that occur in equation (10). In both specifications the estimated coefficients are similar. In the following analysis we will therefore focus on the more robust FE estimation. Recall that if subjects behave optimally or deviate randomly from optimal consumption, the estimated coefficients β_1 to β_5 should equal one. For β_1 , the data reject this hypothesis. Table 3 shows that the coefficient for current income is sig-

¹¹We suppress henceforth subject and round indices to facilitate legibility.

	OLS		FE	
\tilde{y}	1.158***	(4.42)	1.210***	(5.78)
\tilde{a}	0.700***	(-24.84)	0.891***	(-4.50)
\tilde{J}	0.339***	(-14.18)	0.467***	(-11.31)
$\tilde{\Gamma}(\theta\sigma_y)$	1.598	(0.93)	2.006*	(1.69)
$(T-t)\tilde{y}_p$	1.145*	(1.83)	1.277***	(3.81)
$d_{0.tx}$	19.100***	(5.10)	19.780***	(5.27)
$d_{240.tx}$	-25.660***	(-9.52)	-25.930***	(-9.57)
$d_{t-1,0.tx}$	2.684**	(2.09)	2.910**	(2.29)
$d_{t-2,0.tx}$	3.146***	(2.63)	3.333***	(2.84)
$d_{t-3,0.tx}$	0.066	(0.05)	0.195	(0.15)
$d_{t-1,240.tx}$	-6.560***	(-3.93)	-5.684***	(-3.52)
$d_{t-2,240.tx}$	-0.645	(-0.37)	-0.674	(-0.40)
$d_{t-3,240.tx}$	-4.688***	(-3.44)	-4.620***	(-3.44)
t	-1.629***	(-3.52)	-1.435***	(-3.22)
t^2	0.058**	(2.31)	0.058**	(2.37)
Treatment (base: control):				
dR1	-6.752***	(-2.71)		
dR2	-9.962***	(-3.31)		
Round dummies (base: round 1):				
$d_{r,2}$	5.980***	(2.76)	5.550**	(2.23)
$d_{r,3}$	-1.671	(-0.74)	1.717	(0.64)
$d_{r,4}$	3.922*	(1.77)	3.078	(1.15)
$d_{r,5}$	5.147**	(2.39)	5.338**	(2.09)
$d_{r,6}$	0.431	(0.19)	3.319	(1.30)
$d_{r,7}$	2.103	(0.94)	3.218	(1.28)
$d_{r,8}$	1.022	(0.49)	4.536*	(1.84)
Risk aversion (base: low):				
high	-3.013	(-1.23)		
medium	-2.343	(-0.89)		
Gender (base: male):				
female	4.070*	(1.95)		
Subject (base: economics):				
engineering	1.531	(0.62)		
otherscience	6.001**	(2.11)		
other	4.248	(1.47)		
Constant	-78.430***	(-5.93)	-98.840***	(-7.27)
Adjusted R^2	0.357		0.409	
Overall R^2			0.342	

Notes: The dependent variable is observed consumption (c_{itr}). T statistics based on cluster robust (subject level) standard errors are in parentheses. T statistics and significance levels of the first five regressors refer to tests of the H_0 that the respective variable is equal to 1, significance levels are * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All other t statistics and significance levels refer to tests of the H_0 for which the respective variable is equal to zero; significance levels are * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Source: Own calculations based on data from our experiment.

Table 3: Panel Regression on Observed Consumption.

nificantly higher than one. This implies that individuals react to changes in current income more strongly than optimal. While this finding conflicts with the theory, it is consistent with the notion of excess sensitivity from the empirical literature.¹² Subjects consistently do not only consume too much out of current income, but also out of expected income. The estimate for the coefficient on $(T-t)\tilde{y}_p$ is of similar size; however, it is only statistically marginally different from one in the OLS specification. Subjects do not seem to have correct intuition about what the levels of current and expected income imply for their decision problem, or they simply overreact to income changes.

The coefficient on savings indicates that subjects do not spend enough out of wealth since the estimate is statistically smaller than one. This could again stem from difficulties in assessing magnitudes, or it could reflect a social norm that deems parsimony as a good thing.

The amount of future due taxes might not have been assessed correctly either. The coefficient is about half of what theory predicts. A *ceteris paribus* interpretation implies that one Taler less (the variable is defined as -1 times the original variable) of future taxes to be paid increases spending by a half Taler instead of one.

The impact of precautionary saving on consumption should be captured by the coefficient on $\tilde{\Gamma}(\theta\sigma_y)$. While the estimated coefficient is approximately twice as high as theory would predict, it is only marginally significantly greater than one in the FE specification and not statistically different from one in the OLS specification.

The coefficients of our particular interest are $\beta_{0.tx}$ and $\beta_{240.tx}$ because they indicate how subjects react to a tax rebate ($\tau_t = 0$) and a tax increase ($\tau_t = 240$). In the FE specification, the estimated coefficient $\beta_{0.tx}$ is 19.78 (p-value: < 0.01). This

¹²See e.g. [Flavin \(1981\)](#); [Hall and Mishkin \(1982\)](#); [Souleles \(1999\)](#); [Shea \(1995\)](#); [Parker \(1999\)](#). Several explanations for excess sensitivity are debated in the literature; in particular, myopic behavior, liquidity constraints, and buffer-stock saving.

implies that a tax rebate of 120 Taler is associated with an increase in consumption of 19.78 Taler. In turn, the estimated coefficient corresponding to a tax increase ($\beta_{240.tx}$) is -25.93 (p-value: < 0.01), implying that an increase in taxes of 120 Taler is associated with a decrease in consumption of 25.93 Taler. These results give account of the average effect of taxation in both Ricardian treatments. However, we are also interested in whether reactions to taxation differ by treatment. We can identify the effects of Ricardian taxation separately by including interaction terms of $d_{0.tx}$ and $d_{240.tx}$, with binary variables indicating treatment Ricardian 1 and Ricardian 2, respectively. In treatment Ricardian 1, the estimated coefficient corresponding to a tax rebate is 10.94 (p-value: < 0.01) and the coefficient corresponding to a tax increase is -28.20 (p-value: < 0.01).¹³ In treatment Ricardian 2 the coefficient corresponding to a tax rebate is 27.63 (p-value: < 0.01) and that corresponding to a tax increase is -23.91 (p-value: < 0.01).¹³ These estimates indicate that subjects react to taxes in a similar way in both treatments. However, the coefficient associated with a tax rebate is significantly higher in the Ricardian 2 treatment compared to Ricardian 1. No significant difference is observed between the coefficients corresponding to a tax increase.

A multi-period life cycle consumption experiment allows to analyze dynamic effects of taxation. The coefficients on the first two lagged tax indicators of a tax rebate are significantly positive. For the tax increases, the first and the third coefficients are significantly negative. This implies that a one-period tax benefit (a one-period tax increase) affects consumption positively (negatively) beyond the current period. To estimate the total effect, we calculate the sum of all significant coefficients associated with tax benefits and tax increases respectively from Table 3.

For a tax benefit, this sum is 26.02. This implies that a tax cut of 120 Taler is

¹³Not reported in Table 3.

linked to a total increase in consumption of 26.02 Taler, or 22% of the tax benefit. For a tax increase, the sum of all significant coefficients is -36.23 , which implies a reduction in consumption of 30% of the tax increase. Including treatment dummies in the OLS specification, the average effect of a tax cut is virtually the same. We therefore conclude that this result is robust to variations in the difficulty to smooth consumption.

This evidence suggests that taxes have a significant and strong effect on consumption. This is in stark contrast with the theoretical predictions, and thus we conclude that the Ricardian proposition is resoundingly rejected by the experimental data. An early tax benefit causes a significant increase in consumption on average. The corresponding later increase in taxation causes a significant decrease in consumption on average.

Our findings account for the average effect of Ricardian taxation on consumption. However, there appears to be some heterogeneity in our experimental data that cannot be controlled for, even with a fixed effects specification. Generally, this occurs when subjects employ different strategies to choose consumption. To identify the share of subjects that behaves in accordance with Ricardian Equivalence, we therefore run individual OLS regressions for each subject, using the same specification as above. We classify the subjects' behavior as follows: if either the coefficient associated with a tax benefit ($\beta_{0.tx}$), the coefficient associated with a tax increase ($\beta_{240.tx}$), or both are significantly different from zero at the 5% level, a subject's behavior is inconsistent with Ricardian Equivalence. In this conservative way, we find that the behavior of approximately 62% of our subjects can be classified as being not consistent with Ricardian Equivalence. If we only require the coefficient associated with a tax benefit ($\beta_{0.tx}$) to be statistically equal to zero at the 5% level, about 36% of our subjects are classified as being not consistent with Ricardian Equivalence.

This finding is similar to those in other studies that employ very different meth-

ods. For instance, [Campbell and Mankiw \(1991\)](#) use aggregate data to find the fraction of consumers who respond to changes in current disposable income to be in the range of 35% to 50% for the United States and lower fractions in other countries. [Shapiro and Slemrod \(1995\)](#) find from a telephone survey that 43% of those who responded said they would spend most of the extra take-home pay.

These results have important implications for theoretical models that build on households's intertemporal consumption choices. Not accounting for a substantial portion of consumers reacting to tax cuts would bias any conclusion based on the assumption of pure Ricardian Equivalence and understate the role fiscal policy plays. Among the studies that recognize this fact and explicitly model two types of consumers are [Mankiw \(2000\)](#) and [Galí, López-Salido, and Vallés \(2004\)](#). The latter study shows that the Taylor principle may become too weak a criterion for stability when the share of rule-of-thumb consumers is large.

The finding that consumers increase consumption when taxes are cut has important policy implications. In our experimental environment, Ricardian taxation leads to welfare losses compared to constant taxation. However, this does not necessarily need to be the case in the real world, where general equilibrium effects that are deliberately abstracted from in our model may play a role. Therefore, future research is needed that appropriately describes the role of fiscal policy to give policy advice. In particular, the magnitude of effects on consumption needs to be quantified. This future research could corroborate the conjecture that in times of economic slowdown, tax cuts could serve as a means to get the economy back on track.

4 Conclusion

In this paper we test whether the Ricardian Equivalence proposition holds in a life cycle consumption laboratory experiment.

Our first main finding is that Ricardian Equivalence does not hold generally. A nonparametric analysis shows that deviations from optimal consumption as well as utility loss appear to be larger with the tax scheme that increases the difficulty to smooth consumption compared to the one that decreases difficulty to smooth consumption. Overall, deviations from optimal behavior are lowest in the treatment with constant taxation. This implies that both difficulty and Ricardian taxation affect consumption behavior.

Our second main result from panel data estimations is that Ricardian taxation has a significant and strong effect on consumption in our sample. A tax benefit in early periods increases consumption by about 22% of the tax benefit on average, while a tax increase causes a reduction by 30% of the tax increase.

Our third main result is that the behavior of a significant portion of our subjects can be classified as inconsistent with the Ricardian Equivalence proposition. A conservative estimation suggests that this portion is about 62%.

References

- ADJI, A., J. ALM, AND P. J. FERRARO (2009): “Experimental Tests of Ricardian Equivalence with Distortionary Versus Nondistortionary Taxes,” *Economics Bulletin*, 29(4), 2556–2572. Cited on page [2](#).
- BALLINGER, T. P., M. G. PALUMBO, AND N. T. WILCOX (2003): “Precautionary Saving and Social Learning Across Generations: An Experiment,” *The Economic Journal*, 113(490), 920–947. Cited on pages [7](#), [8](#), and [13](#).
- BARRO, R. J. (1974): “Are Government Bonds Net Wealth?,” *Journal of Political Economy*, 82(6), 1095–1117. Cited on page [2](#).

- CABALLERO, R. J. (1990): “Consumption Puzzles and Precautionary Savings,” *Journal of Monetary Economics*, 25(1), 113–136. Cited on pages 4, 5, 6, and 28.
- CABALLERO, R. J. (1991): “Earnings Uncertainty and Aggregate Wealth Accumulation,” *The American Economic Review*, 81(4), 859–871. Cited on pages 4, 5, 6, and 28.
- CADSBY, C. B., AND M. FRANK (1991): “Experimental Tests of Ricardian Equivalence,” *Economic Inquiry*, 29(4), 645–664. Cited on page 2.
- CAMPBELL, J. Y., AND N. MANKIW (1991): “The Response of Consumption to Income: A Cross-Country Investigation,” *European Economic Review*, 35(4), 723–756. Cited on pages 4 and 23.
- CARBONE, E., AND J. D. HEY (2004): “The Effect of Unemployment on Consumption: An Experimental Analysis,” *The Economic Journal*, 114(497), 660–683. Cited on pages 5 and 8.
- CARROLL, C. D. (2011): “Solution Methods for Microeconomic Dynamic Stochastic Optimization Problems,” *World Wide Web*: <http://www.econ.jhu.edu/people/ccarroll/solvingmicrodsops.pdf>. (accessed August 30, 2011). Cited on page 28.
- DI LAUREA, D., AND R. RICCIUTI (2003): “An Experimental Analysis of Two Departure from Ricardian Equivalence,” *Economics Bulletin*, 8(11), 1–11. Cited on page 2.
- DUFFY, J. (2012): “Macroeconomics: a survey of laboratory research,” *Handbook of Experimental Economics*, 2. Cited on page 16.

- FISCHBACHER, U. (2007): “z-Tree: Zurich Toolbox for Ready-Made Economic Experiments,” *Experimental Economics*, 10(2), 171–178. Cited on page [11](#).
- FLAVIN, M. A. (1981): “The Adjustment of Consumption to Changing Expectations About Future Income,” *Journal of Political Economy*, 89(5), 974–1009. Cited on page [20](#).
- GALÍ, J., J. D. LÓPEZ-SALIDO, AND J. VALLÉS (2004): “Rule-of-Thumb Consumers and the Design of Interest Rate Rules,” *Journal of Money, Credit and Banking*, 36(4), 739–763. Cited on page [23](#).
- GREINER, B. (2004): “An Online Recruitment System for Economic Experiments,” *Forschung und wissenschaftliches Rechnen*, pp. 79–93. Cited on page [12](#).
- HALL, R. E., AND F. S. MISHKIN (1982): “The Sensitivity of Consumption to Transitory Income: Estimates from Panel Data on Households,” *Econometrica*, 50(2), 461–481. Cited on page [20](#).
- MANKIW, N. G. (2000): “The Savers-Spenders Theory of Fiscal Policy,” *American Economic Review*, 90(2), 120–125. Cited on page [23](#).
- MEISSNER, T. (2013): “Intertemporal Consumption and Debt Aversion: An Experimental Study,” *SFB 649 Discussion Papers*. Cited on pages [4](#), [5](#), [11](#), and [13](#).
- MUSGRAVE, R. A. (1985): “A Brief History of Fiscal Doctrine,” in *Handbook of Public Economics*, ed. by A. J. Auerbach, and M. Feldstein, vol. 1, Chapter 1, pp. 1–59. Elsevier, Amsterdam: North-Holland. Cited on page [2](#).
- PARKER, J. A. (1999): “The Reaction of Household Consumption to Predictable Changes in Social Security Taxes,” *The American Economic Review*, 89(4), 959–973. Cited on page [20](#).

- ROSTAM-AFSCHAR, D., AND J. YAO (2014): “Progressive Taxation and Precautionary Saving,” mimeo. Cited on page 7.
- SEATER, J. J. (1993): “Ricardian Equivalence,” *Journal of Economic Literature*, 31(1), 142–190. Cited on pages 2 and 7.
- SHAPIRO, M. D., AND J. SLEMROD (1995): “Consumer Response to the Timing of Income: Evidence from a Change in Tax Withholding,” *American Economic Review*, 85(1), 274–83. Cited on pages 4 and 23.
- SHEA, J. (1995): “Union Contracts and the Life-Cycle/Permanent-Income Hypothesis,” *American Economic Review*, 85(1), 186–200. Cited on page 20.
- SLATE, S., M. MCKEE, W. BECK, AND J. ALM (1995): “Testing Ricardian Equivalence under Uncertainty,” *Public Choice*, 85(1-2), 11–29. Cited on page 2.
- SOULELES, N. S. (1999): “The Response of Household Consumption to Income Tax Refunds,” *American Economic Review*, 89(4), 947–958. Cited on page 20.
- ZELDES, S. P. (1989): “Optimal Consumption with Stochastic Income: Deviations from Certainty Equivalence,” *The Quarterly Journal of Economics*, 104(2), 275–298. Cited on page 7.

A Optimal Consumption with CARA Preferences

Following [Caballero \(1990, 1991\)](#), assume that optimal consumption follows an AR(1)-Process:

$$c_{t+1} = c_t + \Gamma_t + \nu_{t+1}, \quad (12)$$

Since the income generating process follows a discrete uniform distribution, the error of the consumption process should follow the same distribution. Define the stochastic error as $\nu_{t+1} = \zeta_{t+1}\varepsilon_{t+1}$ with

$$\varepsilon_{t+1} = \begin{cases} 1 & \text{with probability } 1/2 \\ -1 & \text{with probability } 1/2. \end{cases}$$

Where ζ_t is the standard deviation of consumption in period t . From the numerical solution¹⁴, we observe that ζ_t grows between periods t and $t + 1$ in the following way:

$$\zeta_{t+1} = \frac{T - t + 1}{T - t} \zeta_t. \quad (13)$$

We can therefore write:

$$c_{t+1} = c_t + \Gamma_t + \frac{T - t + 1}{T - t} \zeta_t \varepsilon_{t+1}, \quad (14)$$

Now we need to pin down Γ_t . We start from the Euler equation

$$1 = E_t[\exp^{-\theta(c_{t+1} - c_t)}]. \quad (15)$$

Plugging (12) in (15) yields

¹⁴We followed [Carroll \(2011\)](#) to obtain the numerical solution.

$$\Gamma_t = \frac{1}{\theta} \log \{E_t[\exp^{-\theta \nu_{t+1}}]\} = \quad (16)$$

$$= \frac{1}{\theta} \log [1/2 \exp^{-\theta \zeta_{t+1} \varepsilon_{t+1}} + 1/2 \exp^{\theta \zeta_{t+1} \varepsilon_{t+1}}] \quad (17)$$

$$= \frac{1}{\theta} \log \cosh[\theta \zeta_{t+1}]. \quad (18)$$

$$\Gamma_t = \frac{1}{\theta} \log \cosh \left[\theta \frac{T-t+1}{T-t} \zeta_t \right]. \quad (19)$$

Iteration of (12) from t to $t+j$ gives

$$c_{t+j} = c_t + \sum_{i=1}^j \Gamma_{t+i-1} + \sum_{i=1}^j \nu_{t+i}, \quad (20)$$

where

$$\sum_{i=1}^j \Gamma_{t+i-1} = \sum_{i=1}^j \frac{1}{\theta} \log \cosh \left[\theta \frac{T-t+1}{T-t+1-i} \zeta_t \right], \quad (21)$$

$$\sum_{i=1}^j \nu_{t+i} = \sum_{i=1}^j \frac{T-t+1}{T-t+1-i} \zeta_t \varepsilon_{t+i}. \quad (22)$$

Iteration of (20) from $t+j$ to $T-t$ gives

$$\sum_{j=0}^{T-t} c_{t+j} = (T-t+1)c_t + \sum_{j=0}^{T-t} \sum_{i=1}^j \Gamma_{t+i-1} + \sum_{j=0}^{T-t} \sum_{i=1}^j \nu_{t+i}. \quad (23)$$

The iterated intertemporal budget constraint is

$$\sum_{j=0}^{T-t} c_{t+j} = a_t + \sum_{j=0}^{T-t} y_{t+j} - \sum_{j=0}^{T-t} \tau_{t+j}, \quad (24)$$

where $E_t[\sum_{j=0}^{T-t} y_{t+j}] = y_t + (T-t)y_p$ and $y_p = E[y_t]$.

Therefore, taking expectations gives

$$\begin{aligned} (T-t+1)c_t + \sum_{j=0}^{T-t} \sum_{i=1}^j \Gamma_{t+i-1} + \sum_{j=0}^{T-t} \sum_{i=1}^j \frac{T-t+1}{T-t+1-i} \zeta_t \underbrace{E_t[\varepsilon_{t+i}]}_{=0} \\ = a_t + y_t + (T-t)y_p - \sum_{j=0}^{T-t} \tau_{t+j}. \end{aligned} \quad (25)$$

Solving for c_t gives

$$c_t = \frac{1}{T-t+1} \left(a_t + y_t + (T-t)y_p - \sum_{j=0}^{T-t} \tau_{t+j} - \sum_{j=0}^{T-t} \sum_{i=1}^j \frac{1}{\theta} \log \cosh \left[\theta \frac{T-t+1}{T-t+1-i} \zeta_t \right] \right). \quad (26)$$

From equation (13) we know that

$$\zeta_t = \frac{\zeta_T}{T-t+1}. \quad (27)$$

Since the marginal propensity to consume in the last period is 1, we know that the standard deviation of the consumption process must equal the standard deviation of the income process, $\zeta_T = \sigma_y$. Therefore we can write:

$$c_t^* = \frac{1}{T-t+1} [a_t + y_t + (T-t)y_p - \mathcal{T}_t - \Gamma_t(\theta\sigma_y)], \quad (28)$$

$$\Gamma_t(\theta\sigma_y) = \sum_{j=0}^{T-t} \sum_{i=1}^j \frac{1}{\theta} \log \cosh \left[\frac{\theta\sigma_y}{T-t+1-i} \right], \quad (29)$$

$$\mathcal{T}_t = \sum_{j=0}^{T-t} \tau_{t+j} = \vartheta - \sum_{j=1}^{t-1} \tau_j. \quad (30)$$

B Instructions

This section contains the instructions of the experiment.¹⁵ Subjects in all treatments received the same instructions.

Instructions

Welcome to this experiment!

During this experiment you are not allowed to use electronic devices or to communicate with other participants. Please only use programs provided for this experiment. Please do not talk to other participants. If you have a question, please raise your hand. We will then come to you and answer your question individually. Please do not ask your question out loud. If your question is relevant for all participants, we will repeat your question out loud.

Overview. First you will have time to read the instructions. After that we will go through the instructions together, and you will complete a quiz in order to make sure you understood the instructions. The experiment consists of 8 rounds, each of which consists of 25 periods. The duration of the experiment is around 1.5 hours. Instructions, quiz, and a questionnaire will take around 30 minutes. The remaining hour is dedicated to the actual experiment. After the last round, your experiment payoff will be displayed. Please raise your hand when you have finished the last period. You will then be handed a short questionnaire. After filling out the questionnaire, please raise your hand again. You will then receive your experiment payoff in the adjacent room.

¹⁵The instructions printed here are a translation of the original German version.

Your task is to decide in every period how many *points* you want to purchase. The sum of all points purchased in one round is that period's result. Your payoff depends on the results from two randomly drawn rounds.

Income, Savings and Wealth. In every period you obtain a certain *income*, denoted in the experimental currency "Taler". From this income you have to pay a certain amount of taxes to the government. Your task is to choose how many Taler to spend in order to purchase points. Thereby you (implicitly) also choose how many Taler you want to save or borrow. We call your income minus spending and taxes in one period *savings*.

Your *wealth* in the first period of every round is 1,000 Taler (initial wealth). The wealth in every later period equals the wealth of the previous period plus savings (=income-spending-taxes) of the previous period.

Please note that the sign of the savings can be either positive or negative. If you decide to spend fewer Taler than you have as income minus taxes, your savings have a positive sign. In this case your wealth in the next period is your wealth in this period plus the absolute amount of savings in this period. Should you decide to spend more Taler than you have as income, your savings have a negative sign. In this case your wealth in the next period is your wealth in this period minus the absolute amount of savings.

Example: assume your income in one period is 50 Taler and you have to pay 10 Taler in taxes. If you spend 30 Taler to purchase points, your savings are 10 Taler. In case you instead spend 70 Taler with the same income, your savings are -30 Taler. In the first case your wealth in the next period is the wealth in this period plus 10 Taler. In the latter case your wealth in the next period is this period's wealth minus 30 Taler.

Your wealth may take positive or negative values as well, depending on whether your savings from previous periods plus your initial wealth were positive or negative. In the last period, your wealth plus income minus taxes will be spent automatically in order to purchase points. This implies that the sum of Taler spent in all periods of one round equals the sum of income obtained in all periods of this round minus the sum of all taxes paid in this round. In other words: you may spend more or less than your income in one round. However, over one round, the sum of income plus initial wealth always equals the sum of Taler spent plus the sum of all taxes.

Determination of Income and Taxes. Your income is randomly determined. In every period, your income can take the values of either 250 Taler or 120 Taler. Both values occur with the equal probability of 50%. It is very important to understand that income is truly randomly determined. The value the income takes in one period does not depend on the values it had in previous periods or how you behaved in previous periods.

The government has fixed costs of 120 Taler in every period, which you have to finance through taxes. This implies that the government collects a total of $120 \times 25 = 3000$ Taler from you in the course of one round. The government is free to collect more or less than 120 Taler in taxes in any period. Before you decide how much to spend in every period you learn the amount of taxes the government collects from you in the respective period.

Taler and Points. Your task to decide in every period how many Taler you want to spend in order to purchase points. Taler are transformed to points as follows:

$$\text{Points} = 338 \times \left(1 - e^{-0.0125 \times (\text{chosen amount of Taler})}\right)$$

A graph of this function, as well as a table with relevant function values is attached

to the instructions.¹⁶ Please note that the above function is defined in the positive as well as the negative domain. If you choose to spend a negative amount of Taler, you receive a negative amount of points. In this case you “sell” points and gain Taler. Should your wealth plus income in the last period be negative, you will have to automatically sell points in order to make sure that your Taler account is balanced.

Payoff. For your participation you will receive a fixed amount of 21 €. Additionally you will receive an amount that depends on the results of two randomly drawn rounds. This amount is calculated as follows:

$$\text{Payoff in Euro} = \frac{(\text{Result1} - 5000) + (\text{Result2} - 5000)}{100}$$

where Result1 is the first randomly drawn result and Result2 is the second randomly drawn result.

Example: suppose the first randomly drawn result is 5500 points and the second randomly drawn result is 6000 points. Your payoff is then:

$$\frac{(5500 - 5000) + (6000 - 5000)}{100} = \frac{1500}{100} = 15 \text{ €}.$$

Should the payoff calculated according to the formula above fall below 0 € this will be counted as 0 €. In any case you will receive the fixed amount of 5 €. This implies that you will earn *at least* 5 €.

Quiz and Questions. You will now be asked to answer a short quiz regarding the contents of these instructions. In case you have questions after that, please raise your hand. An experimenter will then come to you and answer your question.

¹⁶Omitted here.

Runde: 1

Periode: 11

Ihr Einkommen in dieser Periode (in Taler): 250.00

Ihre Steuern in dieser Periode (in Taler): 120.00

Einkommen - Steuern (in Taler): 130.0

Ihr Vermögen in dieser Periode (in Taler): 716.00

Einkommen + Vermögen - Steuern (in Taler): 846.00

Bitte geben Sie den Betrag ein den Sie ausgeben möchten um Punkte zu erwerben (in Taler):

OK

Sie sparen in dieser Periode (in Taler): 130.00

Ihr Vermögen in der nächsten Periode (in Taler): 846.00

Ihre Ausgaben in dieser Periode (in Taler): 0.00

Erworbene Punkte: 0.00

Weiter

Periode	Runde	Einkommen	Steuern	Summe der gezahlten Steuern	Vermögen	Ausgaben (Taler)	Erworbene Punkte	Punktestand
1	1	120.00	0.00	0.00	1000.00	98.00	238.71	238.71
2	1	120.00	0.00	0.00	1022.00	100.00	241.16	479.87
3	1	120.00	0.00	0.00	1042.00	100.00	241.16	721.03
4	1	120.00	120.00	120.00	1062.00	98.00	238.71	959.74
5	1	250.00	120.00	240.00	964.00	100.00	241.16	1200.90
6	1	250.00	120.00	360.00	994.00	105.00	247.03	1447.93
7	1	120.00	120.00	480.00	1019.00	110.00	252.54	1700.47
8	1	120.00	120.00	600.00	909.00	110.00	252.54	1953.01
9	1	250.00	120.00	720.00	799.00	108.00	250.38	2203.39
10	1	120.00	120.00	840.00	821.00	105.00	247.03	2450.42

Figure 2: Screenshot of the Experimental Interface.

SFB 649 Discussion Paper Series 2014

For a complete list of Discussion Papers published by the SFB 649, please visit <http://sfb649.wiwi.hu-berlin.de>.

- 001 "Principal Component Analysis in an Asymmetric Norm" by Ngoc Mai Tran, Maria Osipenko and Wolfgang Karl Härdle, January 2014.
- 002 "A Simultaneous Confidence Corridor for Varying Coefficient Regression with Sparse Functional Data" by Lijie Gu, Li Wang, Wolfgang Karl Härdle and Lijian Yang, January 2014.
- 003 "An Extended Single Index Model with Missing Response at Random" by Qihua Wang, Tao Zhang, Wolfgang Karl Härdle, January 2014.
- 004 "Structural Vector Autoregressive Analysis in a Data Rich Environment: A Survey" by Helmut Lütkepohl, January 2014.
- 005 "Functional stable limit theorems for efficient spectral cointegration estimators" by Randolph Altmeyer and Markus Bibinger, January 2014.
- 006 "A consistent two-factor model for pricing temperature derivatives" by Andreas Groll, Brenda López-Cabrera and Thilo Meyer-Brandis, January 2014.
- 007 "Confidence Bands for Impulse Responses: Bonferroni versus Wald" by Helmut Lütkepohl, Anna Staszewska-Bystrova and Peter Winker, January 2014.
- 008 "Simultaneous Confidence Corridors and Variable Selection for Generalized Additive Models" by Shuzhuan Zheng, Rong Liu, Lijian Yang and Wolfgang Karl Härdle, January 2014.
- 009 "Structural Vector Autoregressions: Checking Identifying Long-run Restrictions via Heteroskedasticity" by Helmut Lütkepohl and Anton Velinov, January 2014.
- 010 "Efficient Iterative Maximum Likelihood Estimation of High-Parameterized Time Series Models" by Nikolaus Hautsch, Ostap Okhrin and Alexander Ristig, January 2014.
- 011 "Fiscal Devaluation in a Monetary Union" by Philipp Engler, Giovanni Ganelli, Juha Tervala and Simon Voigts, January 2014.
- 012 "Nonparametric Estimates for Conditional Quantiles of Time Series" by Jürgen Franke, Peter Mwita and Weining Wang, January 2014.
- 013 "Product Market Deregulation and Employment Outcomes: Evidence from the German Retail Sector" by Charlotte Senftleben-König, January 2014.
- 014 "Estimation procedures for exchangeable Marshall copulas with hydrological application" by Fabrizio Durante and Ostap Okhrin, January 2014.
- 015 "Ladislaus von Bortkiewicz - statistician, economist, and a European intellectual" by Wolfgang Karl Härdle and Annette B. Vogt, February 2014.
- 016 "An Application of Principal Component Analysis on Multivariate Time-Stationary Spatio-Temporal Data" by Stephan Stahlschmidt, Wolfgang Karl Härdle and Helmut Thome, February 2014.
- 017 "The composition of government spending and the multiplier at the Zero Lower Bound" by Julien Albertini, Arthur Poirier and Jordan Roulleau-Pasdeloup, February 2014.
- 018 "Interacting Product and Labor Market Regulation and the Impact of Immigration on Native Wages" by Susanne Prantl and Alexandra Spitz-Oener, February 2014.

SFB 649, Spandauer Straße 1, D-10178 Berlin
<http://sfb649.wiwi.hu-berlin.de>

This research was supported by the Deutsche
Forschungsgemeinschaft through the SFB 649 "Economic Risk".



SFB 649 Discussion Paper Series 2014

For a complete list of Discussion Papers published by the SFB 649, please visit <http://sfb649.wiwi.hu-berlin.de>.

- 019 "Unemployment benefits extensions at the zero lower bound on nominal interest rate" by Julien Albertini and Arthur Poirier, February 2014.
- 020 "Modelling spatio-temporal variability of temperature" by Xiaofeng Cao, Ostap Okhrin, Martin Odening and Matthias Ritter, February 2014.
- 021 "Do Maternal Health Problems Influence Child's Worrying Status? Evidence from British Cohort Study" by Xianhua Dai, Wolfgang Karl Härdle and Keming Yu, February 2014.
- 022 "Nonparametric Test for a Constant Beta over a Fixed Time Interval" by Markus Reiß, Viktor Todorov and George Tauchen, February 2014.
- 023 "Inflation Expectations Spillovers between the United States and Euro Area" by Aleksei Netšunajev and Lars Winkelmann, March 2014.
- 024 "Peer Effects and Students' Self-Control" by Berno Buechel, Lydia Mechtenberg and Julia Petersen, April 2014.
- 025 "Is there a demand for multi-year crop insurance?" by Maria Osipenko, Zhiwei Shen and Martin Odening, April 2014.
- 026 "Credit Risk Calibration based on CDS Spreads" by Shih-Kang Chao, Wolfgang Karl Härdle and Hien Pham-Thu, May 2014.
- 027 "Stale Forward Guidance" by Gunda-Alexandra Detmers and Dieter Nautz, May 2014.
- 028 "Confidence Corridors for Multivariate Generalized Quantile Regression" by Shih-Kang Chao, Katharina Proksch, Holger Dette and Wolfgang Härdle, May 2014.
- 029 "Information Risk, Market Stress and Institutional Herding in Financial Markets: New Evidence Through the Lens of a Simulated Model" by Christopher Boortz, Stephanie Kremer, Simon Jurkatis and Dieter Nautz, May 2014.
- 030 "Forecasting Generalized Quantiles of Electricity Demand: A Functional Data Approach" by Brenda López Cabrera and Franziska Schulz, May 2014.
- 031 "Structural Vector Autoregressions with Smooth Transition in Variances – The Interaction Between U.S. Monetary Policy and the Stock Market" by Helmut Lutkepohl and Aleksei Netsunajev, June 2014.
- 032 "TEDAS - Tail Event Driven ASset Allocation" by Wolfgang Karl Härdle, Sergey Nasekin, David Lee Kuo Chuen and Phoon Kok Fai, June 2014.
- 033 "Discount Factor Shocks and Labor Market Dynamics" by Julien Albertini and Arthur Poirier, June 2014.
- 034 "Risky Linear Approximations" by Alexander Meyer-Gohde, July 2014
- 035 "Adaptive Order Flow Forecasting with Multiplicative Error Models" by Wolfgang Karl Härdle, Andrija Mihoci and Christopher Hian-Ann Ting, July 2014
- 036 "Portfolio Decisions and Brain Reactions via the CEAD method" by Piotr Majer, Peter N.C. Mohr, Hauke R. Heekeren and Wolfgang K. Härdle, July 2014
- 037 "Common price and volatility jumps in noisy high-frequency data" by Markus Bibinger and Lars Winkelmann, July 2014
- 038 "Spatial Wage Inequality and Technological Change" by Charlotte Senftleben-König and Hanna Wielandt, August 2014
- 039 "The integration of credit default swap markets in the pre and post-subprime crisis in common stochastic trends" by Cathy Yi-Hsuan Chen, Wolfgang Karl Härdle, Hien Pham-Thu, August 2014

SFB 649, Spandauer Straße 1, D-10178 Berlin
<http://sfb649.wiwi.hu-berlin.de>

This research was supported by the Deutsche
Forschungsgemeinschaft through the SFB 649 "Economic Risk".



SFB 649 Discussion Paper Series 2014

For a complete list of Discussion Papers published by the SFB 649, please visit <http://sfb649.wiwi.hu-berlin.de>.

- 040 "Localising Forward Intensities for Multiperiod Corporate Default" by Dedy Dwi Prastyo and Wolfgang Karl Härdle, August 2014.
- 041 "Certification and Market Transparency" by Konrad Stahl and Roland Strausz, September 2014.
- 042 "Beyond dimension two: A test for higher-order tail risk" by Carsten Bormann, Melanie Schienle and Julia Schaumburg, September 2014.
- 043 "Semiparametric Estimation with Generated Covariates" by Enno Mammen, Christoph Rothe and Melanie Schienle, September 2014.
- 044 "On the Timing of Climate Agreements" by Robert C. Schmidt and Roland Strausz, September 2014.
- 045 "Optimal Sales Contracts with Withdrawal Rights" by Daniel Krähmer and Roland Strausz, September 2014.
- 046 "Ex post information rents in sequential screening" by Daniel Krähmer and Roland Strausz, September 2014.
- 047 "Similarities and Differences between U.S. and German Regulation of the Use of Derivatives and Leverage by Mutual Funds – What Can Regulators Learn from Each Other?" by Dominika Paula Gałkiewicz, September 2014.
- 048 "That's how we roll: an experiment on rollover risk" by Ciril Bosch-Rosa, September 2014.
- 049 "Comparing Solution Methods for DSGE Models with Labor Market Search" by Hong Lan, September 2014.
- 050 "Volatility Modelling of CO2 Emission Allowance Spot Prices with Regime-Switching GARCH Models" by Thijs Benschop, Brenda López Cabrera, September 2014.
- 051 "Corporate Cash Hoarding in a Model with Liquidity Constraints" by Falk Mazelis, September 2014.
- 052 "Designing an Index for Assessing Wind Energy Potential" by Matthias Ritter, Zhiwei Shen, Brenda López Cabrera, Martin Odening, Lars Deckert, September 2014.
- 053 "Improved Volatility Estimation Based On Limit Order Books" by Markus Bibinger, Moritz Jirak, Markus Reiss, September 2014.
- 054 "Strategic Complementarities and Nominal Rigidities" by Philipp König, Alexander Meyer-Gohde, October 2014.
- 055 "Estimating the Spot Covariation of Asset Prices – Statistical Theory and Empirical Evidence" by Markus Bibinger, Markus Reiss, Nikolaus Hautsch, Peter Malec, October 2014.
- 056 "Monetary Policy Effects on Financial Intermediation via the Regulated and the Shadow Banking Systems" by Falk Mazelis, October 2014.
- 057 "A Tale of Two Tails: Preferences of neutral third-parties in three-player ultimatum games" by Ciril Bosch-Rosa, October 2014.
- 058 "Boiling the frog optimally: an experiment on survivor curve shapes and internet revenue" by Christina Aperjis, Ciril Bosch-Rosa, Daniel Friedman, Bernardo A. Huberman, October 2014.
- 058 "Expectile Treatment Effects: An efficient alternative to compute the distribution of treatment effects" by Stephan Stahlschmidt, Matthias Eckardt, Wolfgang K. Härdle, October 2014.
- 060 "Are US Inflation Expectations Re-Anchored?" by Dieter Nautz, Till Strohsal, October 2014.

SFB 649, Spandauer Straße 1, D-10178 Berlin
<http://sfb649.wiwi.hu-berlin.de>

This research was supported by the Deutsche
Forschungsgemeinschaft through the SFB 649 "Economic Risk".



SFB 649 Discussion Paper Series 2014

For a complete list of Discussion Papers published by the SFB 649, please visit <http://sfb649.wiwi.hu-berlin.de>.

- 061 "Why the split of payroll taxation between firms and workers matters for macroeconomic stability" by Simon Voigts, October 2014.
- 062 "Do Tax Cuts Increase Consumption? An Experimental Test of Ricardian Equivalence" by Thomas Meissner, Davud Rostam-Afschar, October 2014.

SFB 649, Spandauer Straße 1, D-10178 Berlin
<http://sfb649.wiwi.hu-berlin.de>

This research was supported by the Deutsche
Forschungsgemeinschaft through the SFB 649 "Economic Risk".

